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This project determined (a) that neither thermographs or podoscopes can be used to predict which basic trainees are likely to develop significant lower limb pain during training, (b) that thermography is not clinically useful in tracking changes in training related lower limb pain, (c) that contact thermographs are not useful in the TMC environment due to their inaccuracy, that videothermographs are too cumbersome and expensive to use relative to the information provided in the TMC environment, but that infrared beam thermometers are valuable adjuncts to assessment and tracking, (d) that having trainees wear shock absorbing inserts throughout basic training does not reduce the incidence and severity of lower limb pain, and (e) that training related stress fractures probably do heal faster when exposed to pulsing electromagnetic fields.

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Richard A. Sherman 12 December, 1994

Richard A. Sherman, LTC, MS

Use of body surface heat patterns for predicting and evaluating acute lower extremity pain among soldiers

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Use of body surface heat patterns for predicting and evaluating acute lower extremity pain among soldiers

1. INTRODUCTION:

a. Aims: To determine the usefulness of (1) surface heat patterns for predicting and evaluating acute lower extremity pain among soldiers, (2) shock absorbing inserts in preventing lower extremity pain, and (3) exposing basic trainees with tibial and metatarsal stress fractures to pulsing electromagnetic fields (PEMFs).
This study was performed in two phases. The first project of phase one used heat patterns to detect abnormal blood flow patterns in the lower limbs of recruits who had not yet begun their training. It also recorded the way they put pressure on their feet when standing. The aim of this portion of the study was to develop predictors of problems which develop during training. The second project in phase one compared the effectiveness of three methods for recording surface heat patterns in order to determine which might be appropriate for use in the field environment.
Phase two contained three overlapping projects. The first determined whether having trainees begin using shock absorbing inserts in both their sneakers and boots prior to beginning basic training reduced the occurrence of lower limb pain. The second determined whether videothermography is a valuable tool to use in fixed medical facilities to screen soldiers with pain and to track the resolution of the pain once treatment has been initiated. The third determined whether exposure to pulsing electromagnetic fields reduced the time basic trainees required to recover from stress fractures.

b. Hypotheses for phase two:

(1) That heat patterns in the lower limbs will change consistently and predictably as lower limb pain disorders resolve so that they will be useful for: (a) objectively tracking changes in the problems (which also permits objective determination of whether a treatment is effective), (b) predicting rate of improvement so estimates of when soldiers may be able to return to duty can be made, and (c) assisting in the determination of when a problem is sufficiently resolved so that a soldier can return to duty.

(2) That the use of shock absorbing boot and sneaker inserts will produce a significant reduction (of about 25%) in number of visits to the clinic for lower limb pain and severity of lower limb injuries along with a corresponding increase in PT scores and number of trainees graduating on time. There should also be a corresponding decrease in abnormal thermographic recordings.

(3) That exposure to pulsing electromagnetic fields (PEMFs) will reduce the number of days between diagnosis of training related stress fractures and return to full duty.

c. Objectives for the entire project:

(1) To demonstrate the usefulness of thermography for identifying the presence of vascular related lower limb pain problems and tracking the resolution of those problems throughout treatment.

(2) To avail the medical practitioner with a field viable, convenient, non-invasive, quick, and accurate modality for the diagnosis of stress fracture in

troops by establishing the efficacy of standard beam infrared thermometers normally found in Army rooms.

(3) To determine the ability of shock absorbing boot and sneaker inserts to reduce the occurrence of lower limb pain and abnormal thermograms during basic training.

(4) To determine whether exposure to PEMFs will reduce the number of days between diagnosis of training related stress fractures and return to full duty.

f. Goals:

(1) For the first phase of the project: See the annual report dated 31 January, 1992.

(2) For the second phase of the project:

(a) Determine whether having trainees wear shock absorbing inserts in their sneakers and boots throughout basic training reduces the rate of occurrence of lower limb pain and abnormal thermograms.

(b) Determine whether videothermography is effective in fixed facilities for screening lower limb pain and for tracking its resolution and whether standard infrared beam thermometers can replace videothermographs for this purpose.

(c) To determine whether exposure to PEMFs will reduce the number of days between diagnosis of training related stress fractures and return to full duty.

2. BODY:

a. Prediction of lower limb pain

(1) Thermography: This work has been compiled into an article entitled " Prediction and portrayal of lower limb pain disorders among soldiers in basic training using videothermography" which forms Appendix I. It concludes that thermography can not be used to predict which trainees are likely to develop significant lower limb pain.

(2) Podoscope: A podoscope is a low stool with a transparent top. A mirror is mounted under the top at an angle so that a camera mounted behind the device at about the level of the transparent top can picture both the backs of the calves and the bottom of the feet on one frame. This permits evaluation of both how people stand and how the bottom of the foot is shaped when stood upon. Virtually every solder who participated in the above thermographic study also had podoscopic photos taken prior to beginning basic training. There were no consistent relationships between podoscopic photographs and development of lower limb problems during basic training.

b. Preventive use of shock absorbing inserts: This work has been compiled into an article entitled "Prevention of lower limb pain among soldiers in basic training using shock absorbing boot and sneaker inserts " which forms Appendix II. They do not help reduce the rate of injuries.

c. Comparison of thermographic techniques: This work has been compiled into an article entitled "Comparative effectiveness of videothermography, contact thermography, and infrared beam thermography for scanning skin temperature" which

forms Appendix III. Neither contact nor videothermography are optimal for initial screening in field locations. Infrared thermometers work very well when used in conjunction with a grid diagram of the body.

d. Tracking of limb pain with heat patterns:

(1) Training related pain: Videothermography was not useful for tracking training related pain. There were many false positives and negatives and the information was too non-specific to be used to make decisions on progress. See the following section for details.

(2) Other orthopedic problems: The longitudinal data for RSD have been analyzed and compiled into a publication entitled " Stability of temperature asymmetries in RSD over time, with treatment, and changes in pain." It forms Appendix Four. Data on tracking changes in swelling with thermography was gathered for twenty post hand or foot surgery patients who were evaluated for three weeks post surgery. Thermography was not valuable for tracking swelling but was correlated with healing. Healing did correlate with swelling for the first few days.

e. Treatment of stress fractures using PEMFs:

(1) Objectives: The overall objective was to determine whether exposure to PEMFs after training related stress fractures produced enough of a reduction in days of training lost to warrant proposal of a full study:

(2) Rationale: PEMFs have been shown to be effective in reducing swelling from sprained ankles faster than standard approaches and are approved by the FDA for this use. Selling after hand and foot surgery and after simple fracture of the long bones can frequently be a significant problem resistant to standard techniques including application of ice, elevation, and constriction. When standard techniques are ineffective, surgery is frequently required and patients experience prolonged intense pain. If PEMFs can reduce the swelling further and more rapidly than standard techniques, the duration and intensity of patients' pain and debilitation should be reduced. Stress fractures frequently take months to heal sufficiently for even young, otherwise healthy patients to resume their normal levels of activity. If PEMFs can significantly reduce the time for healing, the duration of pain and debilitation should be reduced.

(3) Structure of the pilot study: This was a double blind, placebo controlled pilot study in which the time to return to work, number of hours per day able to stand, and pain patterns among twenty-one patients with radiologically confirmed tibial and metatarsal stress fractures who received the standard treatment and were concurrently exposed to PEMFs five times for week for one hour per day were compared with thirteen similar patients who received placebo PEMFs concurrently with the standard treatment. PEMFs were provided by either fixed position stimulators (eleven subjects) or ambulatory stimulators (ten subjects). In order to be returned to full activity, participants had to demonstrate: the ability to run for two miles without pain or difficulty, no pain on palpation of the fracture site. no vibratory sensitivity. no edema or erythema at the fracture site, and no pain with weight bearing with increased activity. All had positive X-rays prior to treatment and negative X-rays upon return to full activity. All pre and post X-rays were evaluated by the Chief of Orthopedics.

(4) Results: Only data from patients with radiologically confirmed (X-rays and some MRIs) stress fractures of the tibias or metatarsals were included. The subjects exposed to PEMFs generated by fixed site devices returned to their normal levels of activity without pain in an average of 31.7 days (Standard Deviation = 6.8) while the placebo subjects returned in 38.2 (12.5) days. An independent "t" test between the

PEMF and placebo groups did not indicate that the mean difference of 6.5 days was statistically significant ($t = 1.39$ with 19 DF, one tail probability = 0.09). However, A week of time off work is important. There were no differences on any variables for the ambulatory PEMF devices.

(5) Power analysis: A power analysis of "the number of days between diagnosis and return to duty" using Jacob Cohen's Statistical Power Analysis book (Erlbaum, New Jersey, 1988) shows that a total of about 33 subjects will be needed in each group assuming (1) that the Diapulse group is predicted to do better (one-tailed test), (2) an 80% chance of finding a difference between the two groups at a 0.05 level of significance, and (3) no differentiation between types of stress fractures is made. As a full study would require differentiating between types of stress fractures, four groups of 33 subjects completing the study would be required to study both tibial and metatarsal stress fractures. The drop out rate shown in the pilot indicates that about 45 subjects will have to be recruited for each group.

(6) Conclusion: The Army should perform a full study of treatment of stress fractures with fixed site PEMF generators as such treatment is likely to significantly reduce lost training time.

APPENDICES:

1. Sherman R, Karstetter K, Woerman A, and May H: Prediction and portrayal of lower limb pain disorders among soldiers in basic training using videothermography. Accepted for publication by the Clinical Journal of Pain, 1994. Modifications required prior to publication.

2. Sherman R, May H, Karstetter K, and Woerman A: Prevention of lower limb pain among soldiers in basic training using shock absorbing boot and sneaker inserts. Submitted to the Journal of the American Podiatric Association June, 1994.

3. Sherman R, Karstetter K, and Woerman A: Comparative effectiveness of videothermography, contact thermography, and infrared beam thermography for scanning skin temperature. Submitted to Physical Therapy, 1994.

4. Sherman R, Karstetter K, Damiano M, Evans C: Stability of temperature asymmetries in RSD over time, with treatment, and changes in pain. Clinical Journal of Pain, 10(1), 71 - 77, 1994.

Prediction and portrayal of lower limb pain disorders among soldiers in basic training using videothermography

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Abstract

Thermography has been espoused both for detecting and portraying pain problems not displayed by standard medical tests. Development of incapacitating lower limb pain during Army basic training is a relatively common occurrence. Thus, apparently healthy civilians just entering military service are an excellent group upon which to test this claim. Videothermographic pictures were taken of the lower limbs of 639 soldiers who had just arrived at a large US Army base but had not yet begun basic training. The thermography literature consistently states that near surface blood flow in the lower limbs is symmetrical to within one degree Celsius among healthy adults. However, among pre-basic trainees, 37% showed one degree of asymmetry somewhere in their lower limbs, 14% were asymmetrical by at least two degrees, 5% by three, and 4% by four or more degrees. Thus, only 40% of the pre-basic trainees were within accepted "normal" limits. Thirty-nine percent of those with asymmetrical thermograms developed lower limb pain compared with 28 percent of those with symmetrical thermograms (Significant at $p < 0.05$). It was impossible to predict from any thermographic measurement anywhere on the lower limbs which soldiers were most likely to develop lower limb pain. This held true even for those pre-trainees with the greatest asymmetries. Each soldier reporting lower limb pain and "controls" with non-pain problems had additional thermograms. Eighty-four percent of trainees reporting lower limb pain produced abnormal thermograms regardless of whether or not they produced abnormal thermograms prior to training. Thus, thermograms were of little value either for predicting or portraying lower limb pain.

Introduction

1. Lower extremity injury rate during basic training: the US Army Research Institute of Environmental Medicine studied both the incidence and risk factors for injury among Army basic trainees (Jones et al, 1988, Cowan et al 1989). The risk of sustaining lower extremity injuries sufficiently severe to significantly interfere with training was 45% for females and 21% for males. Of these, 11% of females and 2 percent of males sustained stress fractures. In a separate group they found that 129 sustained injuries to their lower extremities which resulted in significant losses of training time. The results of these studies parallel the results of the large demographic and clinical studies reviewed by the authors. These rates of injury become especially noteworthy when it is noted that traumatic events initiating the problems are rare. Volpin et al (1989) recently reviewed 105 lower limb pain cases among recruits and found that 54% had stress fractures when diagnosed using technetium scans. Thus, lower extremity injury during basic training is a very significant factor in training effectiveness.

2. Use of patterns of heat emanating from the body's surface to detect problems in the lower extremities: The use of heat emanating from the body's surface to detect disease processes is of ancient origin. The recent application of modern videothermographic methodology to detect near surface blood flow patterns is simply a refinement of the older techniques of feeling the body's surface. Videothermographs look very much like television cameras and work in a parallel way. The basic difference is that heat emanating from the body's surface is recorded rather than light reflecting off of it as is done with traditional light television. Thus, the system is safe and non-invasive as nothing goes to or touches the subject. Over the last ten years, great strides have been made in increasing the resolution and sensitivity of medical videothermography systems while decreasing their size and operational complexity. For example, the Inframetrics 600M color thermograph used in this study can differentiate between temperatures as little as 0.15 degrees C apart and can visualize areas ranging from one square centimeter to the entire body at once. The unit can quantify differences in heat and record on Polaroid and 35 mm film as well as videotape. A special computer interface/software package permits quantified comparison of many images simultaneously. An absolute

temperature reference always appears on the screen so the actual temperature of an object being viewed is always known and day to day comparisons can be made.

Thermography has been used for differential diagnosis of reflex sympathetic dystrophy (Uematsu et al. 1981, Karstetter and Sherman 1991), rheumatic diseases (Ring 1975), insensitive feet and stumps (Bergtholdt and Brand 1975), diabetic myopathies (Cronin 1975), phantom limb pain (Sherman 1993) chronic pain of unknown origin (Hendler, Uematsu, and Long 1982); as a screen for appropriate amputation level, breast cancer, and cardiovascular disease (Winsor and Winsor 1975), and referred pain (Hobbins 1982). Although no excellent, blinded, comparative technique studies have been performed, thermography has recently been accepted by the AMA as a valid method for assisting in the diagnosis of many conditions and as a primary method for confirming presence of reflex sympathetic dystrophy. Papers such as those by Goodman et al (1985) and Devereaux et al (1984) indicate that thermography is consistently of value in diagnosing stress fractures when compared with results of bone scans. The technique is rapidly gaining wide acceptance for this use.

Typical thermographic studies of chronic pain patients usually either follow a few subjects through a series of evaluations (Sherman et al 1987, Sherman et al 1994) or show the results of one evaluation for a small group of patients with similar diagnoses (Sherman et al 1986). Unfortunately, virtually all articles on the use of thermography for evaluation of chronic pain are very similar in spite of the number of years the technique has been in use and the extensive claims made for its efficacy in detection and demonstration of various pain syndromes discussed above. Other than our own work (e.g. Sherman et al 1987), We have not been able to locate any blind, controlled studies in which such variables as intrasubject change with both time and pain intensity were taken into account. Uematsu is the leading investigator and reviewer in this field (1976) and has published papers (Uematsu 1985, Uematsu et al 1988) in which the stability of temperature differences in paired extremities are compared. Green et al (1986) found a five percent false positive rate when three blinded thermographers evaluated thermograms of 100 normal subjects. Feldman and Nickoloff (1984) have published an extensive set of thermographic standards for normal peoples' upper backs and arms. Although subjects were thermographed only once, the study was large enough to permit definition of the expected range of normal but not expected intrasubject variability. Their paper discusses asymmetries and lists other thermographic studies using normal controls. Virtually all of the above normative studies have shown that the limbs of apparently healthy, pain free, adult subjects are symmetrical to well within one degree of each other.

Methods

Soldiers were thermographed within days of arriving at a major US Army training base prior to being issued uniforms or participating in any training what-so-ever. All of the subjects were males because the particular base participating in the study only trains people for combat arms assignments. At the time the study took place, the Congressional mandate against using females in these roles was still in force.

Subjects were recorded in a temperature regulated environment with drafts reduced to a minimum. Subjects were barefoot and wearing short pants. Each had to wait for the session while laying down with the bottom of the feet in the air for a minimum of 15 minutes to allow body temperature to stabilize. Smoking and use of caffeine and alcohol were normally prohibited for several hours before a thermogram because they effect near surface blood flow. At the end of the equilibration period, the bottoms of the feet were thermographed using an Inframetrics model 600M videothermograph. The instrument was capable of resolving temperature differences of 0.1 degrees Celsius and was sensitive to the heat created by blood flow patterns (spectral range of 8 - 12 micrometers) up to 1.5 cm. deep. Thus, all heat sources in a structure as thin as a foot were visible but only a diffuse reflection of heat sources deep in the leg were directly visible. The device produced color images on a television screen. The video images were recorded on videotape and Polaroid photographs for later computer analysis.

Sensitivity was adjusted so that the computer could differentiate between 0.1 degree C levels. However, during the actual analysis, differences of less than 1.0 degrees were discounted as they were within the most conservative range of normal variation (see the introduction). The model 600M thermograph had an internal temperature reference so the actual temperature of any area visualized could be determined. After the bottom of the feet were thermographed, the subject stood up and the tops of the feet and the front and side of the legs were thermographed while the back of the legs were equilibrating. The backs of the legs were thermographed last. Similar thermographic recordings were made of all recruits reporting to sick call with non-traumatic lower extremity pain at each visit while they were waiting to be seen.

Thermograms of trainees reporting to sick call for non-pain and trauma related problems (e.g. colds) were related to their baselines to establish the expected differences due to training. Their thermograms were related to those of the above trainees reporting lower limb pain to ascertain group differences.

Results

Videothermographic pictures were taken of the lower limbs of 639 soldiers who had just arrived at a large US Army base but had not yet begun basic training. 37% showed one degree of asymmetry somewhere in their lower limbs, 14% were asymmetrical by at least two degrees, 5% by three, and 4% by four or more degrees. Thus, only 40% of the pre-basic trainees were within accepted "normal" limits.

Of 383 trainees who produced asymmetrical baselines in which the limbs were different by at least one degree Celsius (the minimum required for a "clinically" valid difference), 149 (39%) experienced lower limb pain severe enough to require clinical assessment. Of the 256 who produced normal baselines, 72 experienced lower limb pain (28%). While this is a statistically significant difference ($X^2 = 3.89$, $p < 0.05$), it is useless for deciding whether a new recruit should receive special pre-basic training toughening or even not be accepted at all. Of much more importance is the fact that 8 percent of those having lower limb pain sufficient to require treatment had asymmetries greater than 4 degrees while only 2 percent of those not developing lower limb pain ($X^2 = 7.65$, $p = 0.006$). Five percent with pain had differences greater than 5 degrees as opposed to only 1 percent of those not developing pain ($X^2 = 6.46$, $p = 0.01$).

Of 129 trainees seen for non-pain related problems, 92 produced thermograms which were asymmetrical by at least one degree and 62 produced symmetrical ones. Of the 221 trainees reporting lower limb pain, 186 produced asymmetrical thermograms. The relationships between symmetry of pre-training baseline thermograms and of those taken when trainees came to the clinic during training either with or without pain are shown in Table I. The specific problems requiring treatment and the symmetry of the thermograms taken just prior to treatment are shown in Table II.

Discussion

The data clearly show that videothermography is of no value in predicting occurrence of lower limb pain in the population tested. There are so many false positives and negatives that it is also of no value as an objective portrayal of lower limb pain in this group.

Co-variate analyses and correlations which factor out height - weight - body fat ratios, location, description, and intensity of pain, and foot characteristics recorded during the examinations were not performed. Knowing how these factors effect the data might have helped explain some of the variability in the key correlations and thus make the results more powerful but would not make them more meaningful. This is because there would be little value to screening baseline thermograms if a full battery of examinations of far greater than the usual detail have to performed also for the thermograms to be interpreted. In other words, the

thermograms have to stand as alone as possible for them to be valuable predictive tools.

It is possible that our selection of apparently healthy 18 to 24 year old males were somehow radically different from the rest of the population. For example, sixty percent of them might have injured themselves just before coming on active duty while trying to prepare for the strenuous activities they knew were in store for them. This is unlikely because the answers to pre-training questionnaires indicated that most did not make significant changes in their activity levels prior to coming on duty (Sherman et al 1994).

It is also possible that most lied about having lower limb pain before coming on duty and then lied again about having it once they were in. This is unlikely because they all volunteered to come in and conditions in the US Army have changed sufficiently so that the training personnel want soldiers to report their problems early enough so that their overall training is not compromised.

The most likely possibility is that the age range of males we worked with simply have sufficiently variable, asymmetrical blood flow patterns in their lower limbs which precludes the use of thermography as a valuable tool for predicting or portraying their lower limb pain problems.

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Table I

Relationships Between Thermograms Taken Prior to Training and in the Clinic During Training

		Thermograms Taken **Prior to Training**: Thermograms Symmetrical	Thermograms Taken **Prior to Training**: Thermograms Asymmetrical
Patient being treated for **Pain** related problem	Thermograms **S**ymmetrical	28	61
	Thermograms **A**symmetrical	5	21
Patient being treated for **Non-Pain** related problem	Thermograms **S**ymmetrical	15	44
	Thermograms **A**symmetrical	8	13

Table II

Lower Limb Pain Problems for which Soldiers were Treated

Problem Treated For	Total Number with Problem	Pre-training Baseline Thermogram (in garrison)	Thermograms taken during Training (at clinic)
Stress Reaction (in bones)	18	16 Asym	14 Asym 2 Sym
		2 not taken	2 Asym
Stress Fracture	7	6 Asym	6 Asym
		1 not taken	1 Asym
Displaced Fracture	1	1 Sym	1 Sym
Sprains	3	1 Asym	1 Asym
		1 Sym	1 Asym
		1 not taken	1 Asym
Pes Planus	1	1 Sym	1 Sym
Pes Cavus	1	1 Sym	1 Asym
Tendonitis	3	2 Sym	1 Asym 1 Sym
		1 not taken	1 Asym
General Foot Pain	7	5 Asym	2 Asym 2 Sym 1 not taken
		1 Sym	1 Asym
		1 not taken	1 Asym
General Leg Pain	2	2 Asym	2 Asym
Patelofemoral Joint Syndrome (PFJS)	3	1 Asym	1 Asym
		2 Sym	1 Asym 1 Sym
Numbness in Foot	1	1 Asym	1 Asym

Prevention of lower limb pain among soldiers in basic training using shock absorbing boot and sneaker inserts

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Abstract

The utility of shock absorbing boot and sneaker inserts for reducing the occurrence of lower limb pain among male US Army basic trainees was evaluated. Alternate training units were given inserts. The inserts were issued prior to start of training when the combat boots and sneakers were fitted to the trainees. According to both post-training questionnaires and the participants' medical records, the inserts did not have any preventive effect on occurrence of lower limb problems during training. Five hundred and seventeen trainees were issued inserts, 397 were followed but not issued inserts, and 218 were not issued inserts but purchased them on their own. Thirty-eight percent of those issued inserts were seen for lower limb pain problems as opposed to 29 percent of those not issued inserts and 38 percent of those who bought their own. There were no differences between the groups on either training or clinical variables before, during, or after basic training.

Introduction

1. **Lower extremity injury rate during basic training**: Prospective studies conducted by the US Army Research Institute of Environmental Medicine[1,2] found that the risk of sustaining lower extremity injuries sufficiently severe to significantly interfere with training was 45% for females and 21% for males. Of these, 11% of females and two percent of males sustained stress fractures. One hundred and twenty nine sustained injuries to their lower extremities which resulted in significant losses of training time. Nine of these were stress fractures. Illness rates were similar for both sexes (after adjustment for gynecological problems) and only caused a loss of 23 and 19 full training days for women and men respectively. The results of these studies parallel the results of the large demographic and clinical studies reviewed by the authors. These rates of injury become especially noteworthy when it is noted that traumatic events initiating the problems are rare. Volpin et al[3] reviewed 105 lower limb pain cases among recruits and found that 54% had stress fractures when diagnosed using technetium scans. Of the remaining recruits without evidence of stress fractures, 74% had anatomical deformities of the lower limb. Thus, lower extremity injury during basic training is a very significant factor in training effectiveness.

2. **Preventive use of shock absorbing inserts to prevent lower limb pain**: We are aware of only two studies reporting the use of inner soles to prevent overuse injuries. One study[4] used a type of inner sole that did not change vertical impact forces. No change in injury rate was reported. The second study[5] used the same type of cushioning inserts we used in this study. The authors found a decreased incidence of lower limb problems among Army basic trainees. They compared injuries among 237 randomly selected new recruits with injuries among 1151 similar recruits who did not wear inserts. Twenty-one percent of the group wearing cushioned inserts experienced overuse injuries relative to twenty-seven percent of the control group. This difference was significant at the 0.05 level.

3. **Choice of the insert**: The Spenco insert used in this study was chosen because it seemed to work better than the others we have tried clinically and because it had the lowest peak and peak pressure scores but the highest energy return scores of all inserts reviewed[6]. The insert was not supplied gratis by, nor chosen with formal consultation of the manufacturer.

Methods

The study was approved by an Institutional Review Committee and followed all of the relevant Federal and International guidelines for use of human subjects. As trainees reported for basic

training at a large US Army post, they were asked to participate in the study. Inserts were issued to every trainee in alternate basic training units as they were filled by soldiers entering the US Army. Each unit, which is called a battery or company, normally contains several hundred trainees. While the inserts do not require individualized fitting, they do come in shoe sizes. They were fitted to the trainees while they were being given their boots and sneakers during initial uniform distribution. The trainees were instructed to leave the inserts in their foot gear for the entire training cycle and to wear the inserts at all times when on duty. Each trainee from a unit participating in the study was checked for use of the insert by training personnel as part of the normal uniform inspection procedure. Before training, each soldier filled out a short questionnaire concerning prior history of lower limb pain. At the end of basic training, each filled out another questionnaire concerning their use of the inserts.

As the study progressed, word about the study spread to the training units who were not issued inserts. Numerous soldiers in these "control" units purchased the same kind of inserts which were given to solders in the "trial" units. Thus, the data were actually analyzed for three groups rather than two.

The data on (a) physical training test (PT) scores, (b) number of trainees graduating on time, (c) number of visits to the clinic for lower limb pain, (d) severity of lower limb injuries, and (e) changes in lower limb heat patterns were compared for the three groups.

Results

One thousand one hundred and thirty two male trainees participated in the study. Their demographics are detailed in Table One. Only males participated in the study because females were not trained at the participating post.

There were no practical differences between the three groups on factors which might have affected their performance. These factors, including age, height, weight, scores on physical fitness tests, pre-entry exercise, and prior health problems are summarized in Table One. Six percent of trainees starting the study failed to finish basic training on time. However, 53 of those were lost due to pre-existing problems. An additional 16 did not graduate due to psychological problems and 16 failed the PT test. Of considerable interest, only 13 failed to graduate due to being on medical restriction. Thus, less than five percent (55 trainees) of the trainees who were not dismissed due to pre-existing problems failed to graduate on time. Although a third of the soldiers were treated for lower limb pain problems, less than one percent failed to graduate on time due to medical problems. Stress fractures occurred only among 12 trainees and did not prevent most from graduating.

Virtually all of the trainees issued inserts reported using them most of the time. See Table One for a summary of utilization.

Use of inserts did not have any preventive effect on occurrence of lower limb problems during training. Physical training test scores and graduation rates were not affected. Five hundred and seventeen trainees were issued inserts, 397 were followed but not issued inserts and 218 were not issued inserts but purchased them on their own. The inserts purchased were identical to those supplied to the other trainees. Thirty eight percent of those issued inserts were seen for lower limb pain problems as opposed to 29 percent of those not issued inserts and 38 percent of those who bought their own. Table Two summarizes the problems for which these trainees were seen and the amounts of pain they reported. There were no clinically important differences among the groups in problems seen.

The proportions of each variable for the three groups were compared using Chi Square and "t" tests for proportions. None of the groups were different for any of the proportional variables (shown in Tables One and Two). A one way, independent measures, analysis of variance (ANOVA) was used to look for differences among the three groups for the continuous variables of height, weight, age, running time on the physical training test and physical training test scores. Prior to training, the group issued inserts had slightly lower PT test scores of 151 relative to 174 and 173 ($F = 44.06$, $p = 0.0001$) and run times longer by an average of two

seconds (F = 63.96, p = 0.0001). However, all scores were statistically and practically similar by the end of training. Power analyses for both dicotomous and continuous variables showed that sufficient subjects participated to have a 95% chance of detecting a difference of 10% between the groups[7].

Tables One and Two about here

Discussion

The results were surprising because the authors routinely provide inserts of the type utilized in the study to soldiers who experience similar types of lower limb pain caused by similar training. One group consists of patients treated at an Army medical center. These patients are relatively seasoned soldiers and are not training as intensely as the trainees who participated in the study. The problems were corrected among approximately eighty percent of the above soldiers who used the inserts regularly. This is based on a sample of 300 soldiers seen over the last three years with follow-ups on 250 of the soldiers ranging from three to twenty-four months. The other group of patients to whom inserts are regularly provided consists of trainees from the school which eventually participated in the study. When these trainees were evaluated for lower limb pain due to such problems as stress reactions, pes planus (flat feet), and patellofemoral joint syndrome (PFJS), they were issued inserts. The problems were corrected among approximately fifty-five percent of the trainees who used the inserts regularly. This is based on a sample of 400 trainees who had inserts issued to them over the last two years. As the trainees could only get care from the issuing clinic, any trainee who required further medical care would have been noted and their data recorded.

As detailed in the method section, this study was initially designed to have only two groups - one that received inserts and one that did not. Many of the trainees in the group that was not supposed to get inserts purchased their own. Thus, an unexpected third group formed partway through the study. It is possible that those trainees from the "control" group who purchased their own inserts were those who felt that they were likely to have lower limb pain problems during basic training. If their assumption was correct, and if the inserts helped them avoid developing problems, then the self-formed group had the same rate of problems as the other two groups because the inserts helped. If they had been prohibited from purchasing inserts, they might have had more injuries and, thus, the control group would have had a higher incidence of injuries than the group supplied with inserts. This scenario is possible but unlikely because examination of the data from the training units which participated before soldiers began purchasing their own inserts shows no trend towards a difference and the relative numbers are about the same as those finally achieved.

A likely possibility accounting for the lack of a difference between the groups is related to the sensitivity of the participating school to the need for prevention of lower limb injuries and early intervention when initial, relatively minor symptoms occur. The training school had just completed participation in a study intended to identify ways to predict which soldiers were most likely to develop lower limb pain during training. Thus, the training personnel were acutely aware of which symptoms reported by trainees were likely to lead to significant lower limb pain problems in the near future. Most of the trainees reporting such symptoms were referred for care far earlier than they had been prior to initiation of the predictive study and the incidence of serious problems was substantially less than it had been prior to the predictive study. The possibility exists that no difference was found between groups because the overall level of problems was very low relative to pre-study levels. Most of the serious problems were never permitted to occur and minor ones were rectified more quickly than they might have been in units not previously sensitized to symptoms likely to lead to significant debilitation. The results might have been quite different if the study had been done with a "naive" school.

Acknowledgement & disclaimer

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Manufacturer

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TABLE ONE:

Comparison of background factors among soldiers who did and did not use inserts

	Issued inserts	Not Issued inserts	Self-obtained inserts
Total Number:	517	397	218
Demographics (Mean / Standard Deviation):			
Height (cm):	177/6.9	176/7.4	178/8.6
Weight (kg):	75.6/11.7	74.0/11.0	73.1/12.0
Age (yrs):	20.1/2.7	19.8/2.6	19.7/2.6
Pre-entry Exercise:			
Prep for Basic:	64%	62%	59%
Chng Lst 6 mo:	44%	36%	45%
Pre-entry Lower Limb Problems:			
Any Pain:	21%	24%	31%
Serious Injury:	**20%**	**14%**	**19%**
Surgery:	7%	6%	6%
Physical Training Tests (Mean / Standard Deviation):			
Initial Scores:	151/43	174/35	173/36
Final PT Scores:	**213/26**	**210/25**	**211/26**
Initial Run Time:	17/2	15/2	15/2
Final Run Time:	**14/1**	**14/1**	**14/1**
Graduation from Basic Training:			
Graduated on time	92%	95%	94%
Reasons for not graduating on time:			
PT Failure	1.1%	1.7%	1.4%
Psychological	**2.3%**	**0.7%**	**0.4%**
Medical Hold	1.5%	0.7%	0.9%
Recycled	**1.1%**	**0.0%**	**0.0%**
Other	0.0%	0.5%	0.9%
Dismissed for pre-existing conditions:	3.8%	6.8%	2.8%
Frrequency of Use of Inserts:			
Overall: never =	**1.0%**	**-**	**0.5%**
sometimes =	2.2%	-	8.9%
usually =	96.8%	-	90.7%
During PT: nev =	**41.1%**	**-**	**48.1%**
sometimes =	5.5%	-	9.0%
usually =	53.4%	-	42.9%
In Marches: nev =	**1.4%**	**-**	**2.8%**
sometimes =	1.8%	-	4.2%
usually =	96.8%	-	93.1%

TABLE TWO:

Comparison of medical problems among soldiers who did and did not use inserts

	ISSUED INSERTS			NOT ISSUED INSERTS			SELF-OBTAINED INSERTS		
Total # Soldiers Participating	517			397			218		
Overall Summary of Lower Limb Pain Clinic Visits:									
Soldiers seen	195 (37.6%)			116 (29.4%)			81 (38.4%)		
Total Visits	271			191			108		
Categories of medical assessments:									
	Tot #	% of all in group	% of all with low limb pain	Tot #	% of all in group	% of all with low limb pain	Tot #	% of all in group	% of all with low limb pain
Stress RXN/Shin Splints	**33**	**6.4%**	**16.9%**	**15**	**3.8%**	**12.9%**	**14**	**6.6%**	**17.2%**
Stress Fxs	7	1.3%	3.5%	3	0.7%	2.5%	2	0.9%	2.4%
PFJS	**21**	**4.0%**	**10.7%**	**10**	**2.5%**	**8.6%**	**7**	**3.3%**	**8.6%**
Knee (General)	14	2.7%	7.1%	9	2.2%	7.7%	7	3.3%	8.6%
Leg/Foot (General)	**19**	**3.6%**	**9.7%**	**14**	**3.5%**	**12.1%**	**13**	**6.2%**	**16.0%**
Strains/Sprains/Wear	93	17.9%	47.7%	45	11.4%	38.8%	23	10.9%	28.4%
Mechanical/other	**16**	**3.0%**	**8.2%**	**13**	**3.2%**	**11.2%**	**8**	**3.8%**	**9.8%**
Topical/Derm/Blisters	30	5.8%	15.3%	24	6.1%	20.7%	13	6.1%	16.0%
Infections	**9**	**1.7%**	**4.6%**	**5**	**1.2%**	**4.3%**	**2**	**0.9%**	**2.4%**
Multiple Problems	1	0.2%	0.5%	5	1.2%	4.3%	2	0.9%	2.4%
Pain									
Before training: # in pain:	110	21%		97	24%		67	31%	
Pain Rating (Mean / Standard Deviation) (Scale of 0 - 10):	3.8/1.7			4.1/2.0			4.0/1.8		
End of training: # in pain:	197	38%		117	29%		92	42%	
Pain Rating (Mean / Standard Deviation) (Scale of 0 - 10):	4.4/2.0			4.3/2.0			4.2/1.0		

Comparative effectiveness of videothermography, contact thermography, and infrared beam thermography for scanning skin temperature

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Key Words: skin temperature, thermography, measurement, scanning, effectiveness

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Abstract

Background and Purpose: Several techniques for scanning heat patterns on large areas of the skin's surface are becoming accepted adjuncts for diagnosing and tracking various disorders including reflex sympathetic dystrophy, stress fractures, and phantom limb pain. The effectiveness of videothermography, infrared beam thermography, and contact thermography for performing this task were compared in this study. **Method**: The skin over both lower extremities was imaged with each technique sequentially among subjects reporting lower limb pain. Images were also sequentially made of an adjustable, heat producing reference device. One hundred ten of the subjects were otherwise healthy male US Army basic trainees (average age 20.5) being evaluated for reported lower limb pain while forty-four were 29 male and 15 female patients (average age 37.9) at a US Army medical center. **Results and conclusions**: Contact thermography was unable to accurately image areas with curved surfaces and was unable to produce accurate recordings when several sensors ("pillows") with differing temperature ranges had to be used on the same subject. Videothermography was easy to use and produced excellent recordings but was difficult to transport and expensive. An infrared thermometer used in conjunction with a grid map of the body to produce a picture of heat asymmetries between the limbs was the simplest and least expensive system to use for scanning. It was as accurate as videothermography and as quick as contact thermography while avoiding the disadvantages of both. The contact thermographic device did not depict differences in temperatures produced by the heat producing device as accurately as the thermometer or the videothermograph. Information produced by the contract thermograph was frequently contradictory and misleading when multiple sensor "pillows" with different ranges were used.

Introduction

The use of heat emanating from the body's surface to detect disease processes is of ancient origin. The recent application of modern thermographic methodology to detect near surface blood flow patterns is simply a refinement of older techniques of assessing the body's surface temperature.

Medical thermography is still in its infancy but is becoming an accepted medical practice in several areas. Its most common medical use has been in finding objective evidence for reported pain not detectable by other means. For example, positive thermograms can be acceptable in court as evidence used to establish the presence of painful low back disorders [1, 2]. Thermography has been used for differential diagnosis of reflex sympathetic dystrophy [3, 4], rheumatic diseases [5], insensitive feet and stumps [6], diabetic myopathies [7], and phantom limb pain [8]. It has been used to determine the appropriate level for amputation as well as a screen for breast cancer, cardiovascular disease [9], and stress fractures [10, 11]. Thermography has been accepted by the AMA as a valid method for assisting in the diagnosis of many conditions and as a primary method for confirming presence of reflex sympathetic dystrophy.

Other than our own work [12], we have not been able to locate any blind, controlled studies in which such variables as intrasubject change with both time and pain intensity were taken into account. Uematsu [13] is the leading investigator and reviewer in this field and has published papers [14, 15] in which the stability of temperature differences in paired extremities are compared.

The four major ways currently used to evaluate heat emanating from large areas of body surface are electrical thermisters, contact thermography, videothermography, and beam thermography. Any method must be sensitive to differences in paired areas of the body (e.g. the fronts of the left and right knees) and produce consistent recordings over time as these are the measurements reported as useful in the above literature.

(1) Thermisters: Thermisters are sensors which change their electrical resistance with changes in temperature. They are attached to the skin with tape either singly or in arrays. They are simple to use and very accurate but can not be easily used for scanning because (a) take too long to stabilize to be useful in scanning , (b) need to be physically attached (time), and (c) even the largest arrays available can not cover all of the required areas in a reasonable amount of time, and (d) both the sensor and required shielding touch the area to be scanned. Thus, they are not useful for scanning and are not considered further in this study.

(2) Videothermography: Videothermographs look very much like television cameras and work in a parallel way. The basic difference is that heat emanating from the body's surface is recorded rather than light reflecting from it as is done with traditional light television. Thus, the system is safe and non-invasive as nothing radiates to or touches the subject. Most videothermographs can differentiate between temperatures as little as 0.15 degrees C apart and can visualize areas ranging from one square centimeter to the entire body at once. An absolute temperature reference always appears on the screen so the actual temperature of an object being viewed is always known and day to day comparisons can be made. The image produced on the television screen is composed of a series of colors or greytones. Each color represents a temperature range. Thus, if the device is set so that the entire color spectrum displays a range of ten degrees with twenty colors, each color will cover half a degree. Within that color's resolution (half a degree in this example), there is no way to tell the actual temperature of the object being observed other than that it falls somewhere within that half degree range. The alternative is to use options such as electronically generated cross hair sites which can be precisely superimposed on any pixel of the image. The temperature of the pixel at that spot is displayed to the nearest tenth of a degree.

(3) Contact Thermography: Most contact thermograph systems consist of a series of flexible pillow detectors (generally about 18 inches on a side) containing arrays of crystals that change color to correspond to a specific temperature. Crystals sensitive to different temperatures are closely spaced to form "pixels" similar to those which produce color images on a television screen. The pillow is pressed against the part of the body to be visualized. Thus, a color image representing body heat is produced from the color at each pixel. The pillow has a transparent window, allowing the thermographic image to be observed and photographed. Typical contact thermograph systems have eight detector or more pillows so that thermographic images of a wide range of temperatures can be recorded. Similar to the video thermograph, the contact thermograph has a color scale on each window that states what temperature each color corresponds to. This is determined by calibration at the manufacturing plant. Temperature differences that are required to produce the various colors do not occur in standard set increments. Rather, the differences between each color can vary from 0.3 degrees C to 1.1 degrees C. This device is theoretically accurate to within 0.2 degrees C but is very limited in temperature range. It can not be used for long term recordings because the pressure of the plastic screen against the body changes the surface heat patterns.

(4) Infrared "beam" thermometers: Infrared thermometers are now commonly used on wards and in emergency rooms for taking body temperatures instead of standard thermometers. They work the same way as videothermographs but only indicate the temperature of one spot of skin at a time. They are similar to thermisters in that they do not directly produce a heat "picture" of the skin's surface while they are similar to videothermographs in that they do not need to touch the surface to record skin temperature. Since video and infrared beam thermography involve no physical contact

to the patient, this prevents the apparatus from influencing the results and eliminates the need to take additional infectious disease precautions.

Previous studies comparing the ability of these methods to scan large enough areas of the skin's surface for them to be useful in making diagnoses were not found. Togawa [16] provides an excellent review of the methodology for static measurements of skin temperature while Hobbins [17] reviews relationships between skin temperature, thermal measurement, blood flow, and pain.

Methods

1. Subjects: One hundred and fifty-four subjects participated. One hundred and ten of them were otherwise healthy male soldiers in basic training at a large Army post who reported for sick call with lower limb pain without histories of trauma. Their average age was 20.5 years (standard deviation <SD> = 3.2; range of 17 - 34 years) and each was recorded an average of 1.52 times (SD = 0.95). The participating post did not train females so none participated at that site. Forty-four of the subjects (29 males and 15 females) were patients reporting a variety of lower limb pain problems at an Army Medical Center's Psychophysiology Laboratory. Their average age was 37.9 (SD = 15.5; range of 17 - 76 years) and each was recorded an average of 2.1 times (SD = 1.19).

2. Thermographic recordings of people: Subjects were recorded in a temperature regulated environment with drafts reduced to a minimum. Smoking and use of caffeine and alcohol were prohibited for several hours before the evaluations. Subjects were barefoot and wearing short pants. Each waited for the session while sitting with their feet in the air for a minimum of 15 minutes to allow body temperature to stabilize.

At the end of the equilibration period, the plantar surfaces of the feet were thermographed using an Inframetrics* model 600M videothermograph. The instrument was capable of resolving temperature differences of 0.1 degrees Celsius and was sensitive to the heat created by blood flow patterns (spectral range of 8 - 12 micrometers) up to 1.5 Cm. deep. Thus, all heat sources in a structure as thin as a foot would be visible but only a diffuse reflection of heat sources deep in the leg are directly visible. The device produced either grey tone or color images on a television screen. The video images were recorded on videotape and Polaroid photographs for later analysis. Sensitivity was adjusted so that differences of 0.1 degree C levels could be differentiated. The model 600M thermograph had an internal temperature reference so day-to-day changes in temperature could be objectively related. After the plantar surfaces of the feet were thermographed, the subject stood up so the dorsal surfaces of the feet and the fronts and sides of the legs could be thermographed while the back of the legs were equilibrating.

After each videothermographic view was taken, the FirstTemp Model 2000A* infrared thermometer was run along the surface just photographed and measurements were taken along the distal-proximal midline of the surface at approximately 2.5 Cm intervals. After the infrared thermometer was run across the surface, the contact thermograph was pressed against the surface for about 30 seconds and a color photograph was taken of the image produced. The Flexi-Therm Mark II contact thermograph** was used last to eliminate any false patterns that might have been produced by holding an inflated plastic pillow against the skin.

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3. Establishment of linearity and relationships between readings on the three

systems: Any method for measuring heat emanating from the skin's surface is of little use if the readings produced by the instrument are not linear in relation to changes in actual temperature of the skin. Thus, if two points on the skin's surface are 0.8 and 2.7 degrees different from a third point, the instrument must accurately reflect this amount of difference at least proportionately, if not in actual amount. We checked the linearity of all three systems with an AGA* Model 23 variable temperature reference unit. This device consists of a flat black disk about two inches in diameter which radiates heat at a level set by a calibrated dial. Because the surface is flat, the problems inherent in measuring heat from curved body surfaces are reduced significantly. The use of the artificial, flat surface rather than readings from the skin was necessary because, even if the units were apparently pointed at exactly the same point on the skin, they might give different readings due to differences in the angles from which the views were taken. This is because even the smallest curvature in the skin significantly effects the amount of radiation reaching the infrared sensor for the same reasons that the Earth's northern latitudes are cooler than the equator because the essentially parallel rays from the Sun are spread further near the Earth's poles than at the equator.

The videothermograph was set four feet from the reference disk and pointed directly at it with no measurable angle. Four feet was chosen as this is the usual distance from which normal recordings are made. The cross hair site was set to show the center of the reference disk and the temperature was recorded. The thermometer was then applied at a right angle to the center of the disk and its reading was recorded. Then the contact thermograph pillow(s) covering the temperature range was pressed against the reference

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and its reading recorded. The reference was then reset to the next higher temperature. This process was repeated at one degree intervals between 28 and 35 degrees Celsius. This procedure permitted both (a) evaluation of linearity for each instrument and (b) calculation of consistent differences in temperatures measured by the systems.

The videothermograph and the beam thermograph were also evaluated for the similarity of their readings at virtually identical points on the back. This permitted calculation of differences which could be expected in real use but on a relatively flat surface. It also permitted calculation of any consistent differences in number of degrees of difference recorded between paired areas of the body.

Results

1. General: For areas such as the dorsum of the feet whose shape prohibited perpendicular imaging, the temperatures observed with the videothermograph may be different than those taken with an infrared thermometer. This is because the infrared thermometer is always held the same distance from the skin with no angle. The video thermograph shows a very detailed picture of exactly where temperatures are observed. This makes it very easy for the thermographer to concentrate on the specific areas that are affected. The exact point at which the temperature difference is the greatest can easily be detected and recorded. With the infrared thermometer, temperatures were taken at set areas and may not have always reflected the point where the greatest temperature could be observed. This may have diminished the temperature differences observed with the surface temperatures.

All statistics were performed using the Statistical Package for the Social Sciences*.

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2. Linearity and correspondence of the systems:

a. Linearity: The digital temperature reading from the videothermograph was read three times at ten second intervals for each temperature the AGA temperature reference was set at. The reference was gradually changed from 28 to 40 degrees in one degree intervals and permitted to stabilize at each temperature before readings were made. The videothermograph registered virtually one degree increases with each increase of one degree in the reference with the result that there was a 0.994 Spearman's correlation ($p < 0.0001$) between the temperatures registered by the videothermograph and the temperatures produced by the reference. The infrared thermometer was tested similarly. It's readings also went up reliably as the temperature of the reference increased. The Spearman's correlation was 0.990 ($p < 0.0001$). The contact videothermograph was tested similarly but (1) the different pillows did not register similar increases in temperature and (2) several pillows showed the same reaction to different temperatures produced by the reference. Thus, the Spearman's correlation was lower (0.856) but still significant. Even this relatively high correlation is quite misleading as it only shows that the contact thermograph usually indicated an increase in temperature with increased temperature of the reference. The problems with non-linearity of the contact thermography system are illustrated in Figure One.

Figure One about here

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b. Correspondence:

(1) Recordings of the AGA temperature reference: As the AGA system's temperature was increased by one degree increments, the readings on the three devices were recorded. As detailed in the method section, first the videothermograph was pointed at the reference and ten average readings were taken, then ten readings were made with the infrared thermometer held just above the black body, and finally the appropriate contact thermograph pillows were held against it.

One hundred and ninety seven comparisons were made between readings on the contact and video systems (the colors could not be interpreted on three of the contact readings). The Pearson's correlation coefficient was 0.35. When the same comparison was made between the thermometer and the video system, the correlation was 0.97.

(2) Corresponding points on a subject's back: One subject was used to compare readings from the video system and the thermometer. First the video system was pointed at a location on the subject's back (as indicated by the cross hairs on the system) and then the thermometer was held over the same spot by watching the videothermograph's display and lining it up under the cross hairs. The Pearson's correlation coefficient was 0.920 and "r square" was 0.959 using thirty locations on the back. The standard error was 0.155. Because of the very high correlation with a relatively low standard error, the confidence intervals are relatively small so any reading on the thermometer has a 95% chance of being within plus or minus 0.32 degrees of a reading taken by the videothermograph of the same heat source.

As (a) thermography is used by comparing a painful area on one limb (or etc.) with a corresponding point on the "normal," non-painful limb and (b) differences between the points need to reach critical levels (such as one degree Celsius) to be considered clinically significant, it is vital that two instruments show the same amount of difference when measuring corresponding areas. This ability was tested by comparing the readings made by the videothermograph and the thermometer when they were pointed at paired areas on the left and right sides of the subject's back. The Pearson's correlation coefficient for the magnitude of the differences between readings on the left and right

sides was 0.884 with an "r square" of 0.782. The videothermograph showed an average absolute difference between the sides of 1.50 (Standard deviation = 0.94; 99% Confidence Interval = 0.87 - 2.13). The thermometer showed an average absolute difference of 0.81 (SD = 0.56; CI = 0.44 - 1.19).

3. Problems applying the contact thermograph to the lower limbs: The contact thermography system was recalibrated once during the two years the study was in progress. This was because the crystals "drift" and the temperature required to produce a specific color can change over time. The procedure of taking a thermograph by this method involves holding the detector against the patient's skin for about 30 seconds. The detector is then pulled away from the patient to flatten the pillows surface so that the image can be photographed. The thermographic image changes as the detector is taken off the patient's body. If there is a camera malfunction or a time delay of more than a few seconds, the picture will change or be completely lost. Since the pillow detector had to be in a flat position to be photographed without glare, the image appears in a slightly distorted shape, thus the thermographic information may also be distorted. Numerous patients were seen with conditions (especially reflex sympathetic dystrophy) which caused hyperalgesia of the skin. Many found the pain from even the light pressure of the detector too much to withstand. This prevented use of the contact thermograph among these patients. The contact thermograph could not be used with patients having an open wounds, rashes, or fresh surgery scars. During the early stages of the study, attempts to use the contact thermograph to make images of the entire leg and foot area. The size and shape of the leg and foot areas prohibited making a single image of the entire area of interest using one 12 inch by 9 inch pillow. The edges of the detectors would cool the skin and produce a cold line across the skin in the areas that it touched. These factors precluded production of clear images of the entire area of interest.

A specific pillow is chosen so that, ideally, the majority of the thermographic image should appear in the center of the pillow's temperature range. This was often difficult if not impossible. Often a subject's body would be too cold to be observed in the range of even the pillow with the lowest temperature detecting ability. The leg and foot areas often have temperature differences that are greater than a few degrees. With some subject's, the left and the right side could not be observed with the same pillow. This indicated that there was a temperature difference but did not permit determination of what that difference was. This was because the same body area would often produce a different temperature reading with the use of a different pillow. This may not be that critical of a factor since relative differences from right to left are what we are trying to determine. However, since the study showed that temperature differences may occur in the lower limbs that are too great to fit in the range of a single detector, this method is not an effective or accurate diagnostic measurement.

Certain areas of the lower limbs could fit within the field measured by the detectors such as the bottom of the feet. If both the right and left feet are relatively symmetrical in temperature, and there was not much variability in the temperature of the foot from heel to toe, then a relatively clear picture could be obtained. The thermographic trends observed when an adequate thermographic image was obtained followed the trends seen with the other forms of thermography.

Figure Two illustrates Inter-pillow calibration problems which prevent use of contact thermograms for determining absolute differences between limbs which are of too different temperatures to be visualized on the same pillow. Figure Three illustrates the effect of the contact thermograph frame on the ability to properly visualize areas. Figure four shows the effect of the contact thermograph's inability to visualize highly curved surfaces on its ability to detect critical asymmetries.

Figures Two, Three and Four about here

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4. Results of comparisons of the three techniques when used with patients reporting lower limb pain: The videothermograph was consistently simple to use and could visualize all required areas. For those regions upon which the pillow could be pressed, the contact thermograph always showed a difference when the videothermograph showed one. However, the actual amount of difference was usually not calculable due to the problems discussed above. Thus, the device could be used to pick up problems but not to track their progress across sessions.

As demonstrated above, the infrared thermometer almost always showed virtually the same temperature difference as the videothermograph in the experimental trials. Of considerable importance, it could measure the temperature virtually instantly anywhere on the limbs with equal ease. It has none of the problems which make the contact thermograph cumbersome and ineffective. However, it only reads one temperature at a time rather than producing a multitemperature picture of the limb. In order to use the temperatures generated by the thermometer, many measurements must be made on each limb. The measurements must be made of exactly paired areas of the limbs or the measurements are useless. A "picture" of temperature differences is produced by noting differences onto a picture of a limb which is overlaid by a grid. This takes longer than taking a videothermogram but about the same amount of time as it takes to use the contact thermograph. This is because the contact thermograph's pillows have to be changed and adjusted frequently.

According to the literature reviewed in the introduction, patterns of asymmetries useful for current diagnostic tests are a minimum of four Cms. square. A grid diagram of the body was developed on which the temperatures taken by the digital infrared thermometer could be charted to make a temperature diagram of the body similar to that produced by the videothermograph. The grid pattern shown in Figure Five was prospectively tested with 122 lower limb pain subjects (62 of whom were patterned twice) and only missed one small asymmetry on one subject. Other asymmetries on the subject were picked up so the interpretation of the overall body pattern was not changed. This grid has the advantages of permitting an overlay of the location of the patient's pain diagram as well as showing the amount of asymmetry. Figure Five is a copy of an actual transcription made while using the infrared thermometer with the grid. It is provided in its "hand written" state so the data presentation actually achieved can be evaluated for adequacy of meeting readers' needs.

Figure Five about here

Table I lists the relative sensitivities, specificities, predictive values, and efficiencies for the contact system and the thermometer used without the grid. Using the thermometer without the grid meant that the technician was simply moving the thermometer from one side to the other on a patient without any guidance as to how far to go between readings or where to read.

Table One about here

As can be seen from inspection of the table, the results produced by thermometer when used without the grid are not much better than those of the contact thermograph. The large number of false negatives shown by the thermometer at the "one degree of difference" level is largely an artefact of the criteria. As detailed above, the thermometer tends to read somewhat lower than the videothermograph at the lower temperature ranges. Thus, the difference between two relatively cool points will be slightly less for the thermometer than the videothermograph. If a criteria of 0.8 degrees difference was used, the number of false negatives would decrease by 49 to 130 and the

number of true positives would then be 144. This would change the sensitivity to 53%. However, when the thermometer was used with the grid, the videothermograph and the thermometer produced virtually the same results.

Discussion

The contact thermograph was a surprising disappointment. It was cumbersome or impossible to use as required. It could not visualize important areas which have greatly curved surfaces such as the front of the ankles and the back of the knees. Although it is initially enticing to see an apparent image of the extremity's heat produced on a screen, the limitations of that image reduce its value. Due to the very limited range of degrees each pillow is sensitive to, most of the image does not appear. Neither of our sets of contact thermogram pillows were properly calibrated, so the readings from one pillow could not be related to the readings on the one above or below it along the temperature range. This meant that no absolute difference between two limbs could be generated in the frequent case where the temperatures of the limbs are so different that each has to be visualized using a different pillow.

The videothermograph consistently and easily produced superb images of all required areas. However, a videothermograph configured for medical evaluations would cost approximately $45,000, is difficult to move from place to place because it is mounted on one or two carts. Most units require 110 volts of electricity and liquid nitrogen to function.

The infrared thermometer costs less than a few hundred dollars and at least one is probably available at most medical facilities. It seems to be the most valuable of the three devices as: (1) it can take body temperatures virtually instantly without risking contamination of the instrument by touching the patient, (2) does not require a source of line voltage or liquid nitrogen, and (3) can accurately take all required views.

An "image" of temperature asymmetries was produced using this device as quickly as could be done using the contact thermograph. As discussed above, differences between limbs must be noted on an image of the subject's limb rather than just referring to a photograph of an image. However, the notations produce an accurate assessment of the asymmetries while the contact thermograms give a vague notion of problems at best. The grid system can be used by non-professional personnel to produce an accurate picture of both temperature and pain patterns in the lower limbs within five minutes.

Videothermographs are superb for research applications involving visualization of rapid changes in temperature of large skin areas such as required for evaluating changes in near surface blood flow with changes in muscle tension due to contractions <18>. However, no clinical requirements for scanning rapid changes in temperature are in wide use. Problems in the use of thermographic scanning for detection of disease was reviewed by Paul <19>. When thermography is used to confirm the presence of a problem partially diagnosed through other methods, as in confirmation of stress fractures, the clinician already knows exactly where to look based on location of pain and other symptoms so could use an infrared thermometer to identify asymmetries and hot spots. There is no real need to produce an actual image of the area.

It is recommended that any group intending to try thermography for evaluating and/or tracking a medical problem begin with an inexpensive infrared thermometer used in conjunction with a grid such as the one illustrated in Figure Five. If it produces valuable clinical information, one of the other systems may be of more value.

Acknowledgement & Disclaimer

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Legend for Table I

Readings for all three instruments were taken from as close to the same places on the body as could be determined. TP = true positive, TN = true negative, FP = false positive, FN = false negative; Sensitivity = TP/(TP + FN), Specificity = TN/(TN + FP), Specificity = TN/(TN + FP), Predictive Value = TP/(TP + FP), Efficiency = (TP + TN)/all readings. Temperature differences between matched areas on the left and right lower limbs are considered to be important when they are greater than either 0.5 or 1.0 degrees Celsius depending on which literature is accepted so calculations are shown for both levels of difference. The contact thermograph was frequently unable to be placed so it could produce an adequate image of a spot. When this happened, it was counted as a FP if the videothermograph detected an important difference (at either 0.5 or 1.0 depending on the column). The thermometer was used without a grid for this test which means that the readings were relatively random in location relative to those of the videothermograph.

Table I:

RELATIVE EFFECTIVENESS OF THE THREE METHODS

	Video vs. Contact		Video vs. Thermometer (without grid)	
	limbs must differ by $> .5^{\circ}$ for sig	limbs must differ by $> 1^{\circ}$ for sig	limbs must differ by $> .5^{\circ}$ for sig	limbs must differ by $> 1^{\circ}$ for sig
# true negatives	47	74	22	107
# true positives	116	76	275	95
# false negatives	93	49	84	176
# false positives	21	55	6	11
Sensitivity	56%	61%	77%	35%
Specificity	69%	57%	79%	91%
Predictive Value	85%	58%	98%	90%
Overall Efficiency	59%	59%	72%	51%

Legend for Figure One:

Lack of correspondence between pillows in the contact thermography system

Temperatures produced by the temperature reference device are showen in degrees Celsius as measured by the videothermograph. A dashed line with question marks along it at the level of a pillow or leading to question marks indicates that the pillow did not change colors so no reading could be taken for that pillow. Instances where a pillow changed colors but the temperature was clearly above or below its range were not included.

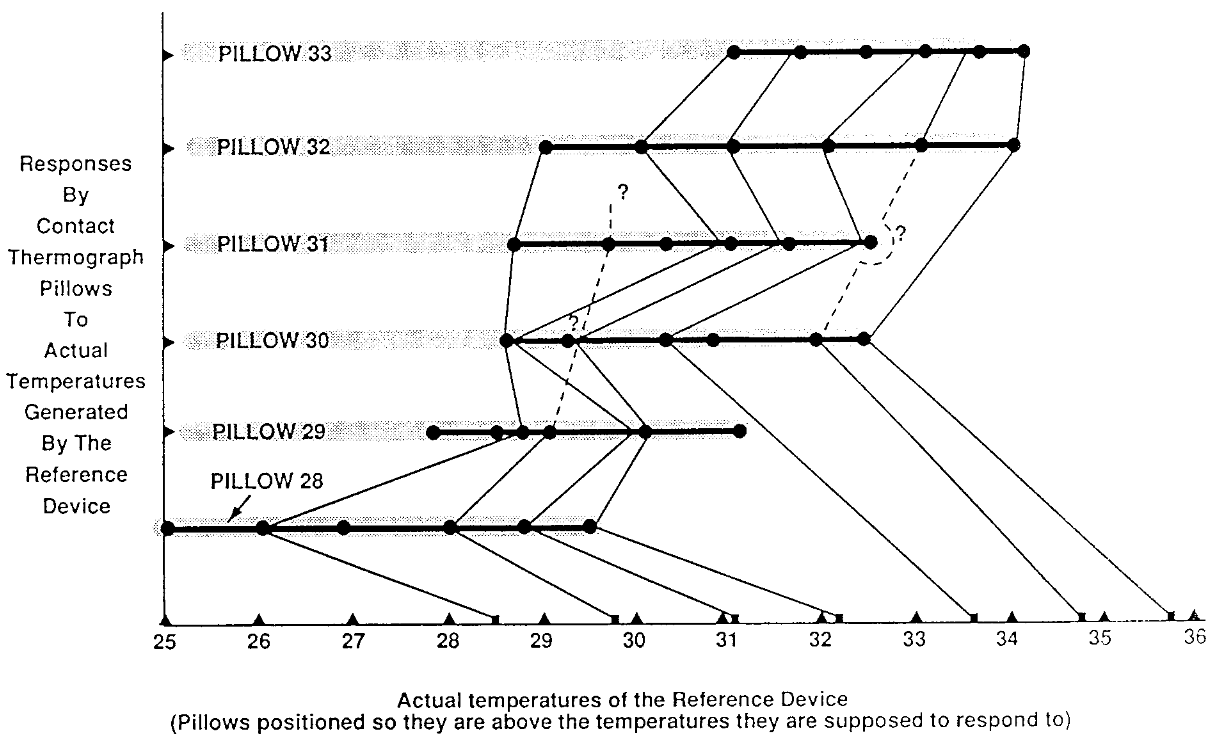
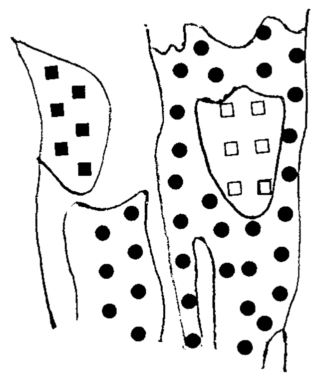


Figure 2

Inter-pillow calibration problems which prevent use of contact thermograms for determining absolute differences between limbs which are of too different temperatures to be visualized on the same pillow

The color Polaroid pictures produced by the thermographs have been redrawn so that different temperatures are shown by different patterns. Significant asymmetries are shown when paired areas of the limbs have different patterns.

A videothermogram showing both limbs is presented below. The areas shown by open and closed squares are 5.4 degrees different. Differences of this magnitude are common and considered to be of clinical importance.



Contact thermograms taken of the same limbs moments later are shown below. Two pillows had to be used to get both limbs into the range of the pillows. The important point here is that the limb shown at the left of each drawing is in range for both pillows. It shows as 29.1 degrees in the left picture (the filled triangles) and as 29.7 degrees in the right picture (the open triangles). This common problem means that the actual difference between two limbs can not be determined when the two have to be visualized using different pillows.

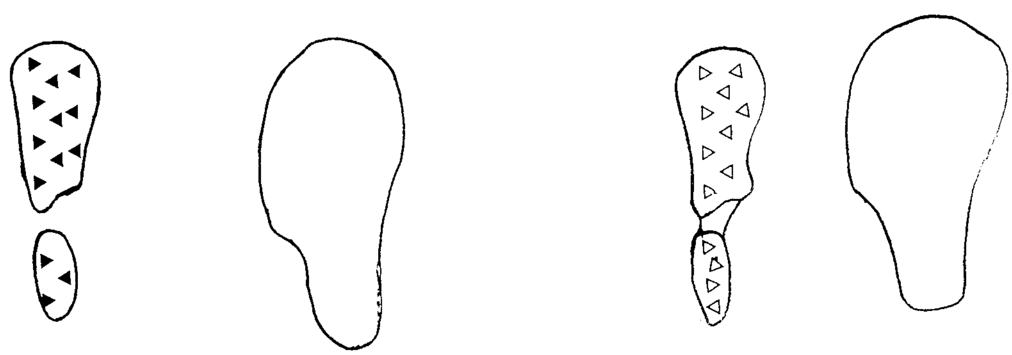


Figure 3

Effect of the contact thermograph frame on ability to properly visualize areas

The redrawn videothermogram on the left contains a crucial area shown by filled triangles which happened to be about the same size as the dark marks left on the skin by the frame of the contact thermograph shown on the right as filled bars. These frame marks prevent proper visualization of an entire limb without waiting for the marks to fade over a period of about ten minutes. This makes the evaluation take so long that it is impractical.

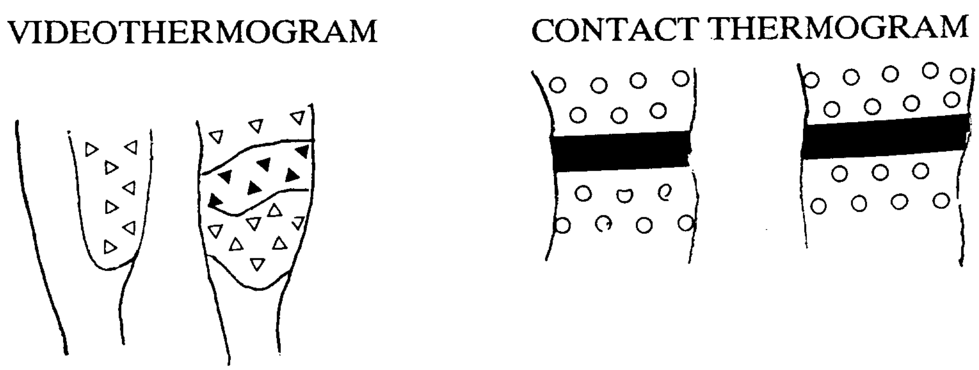
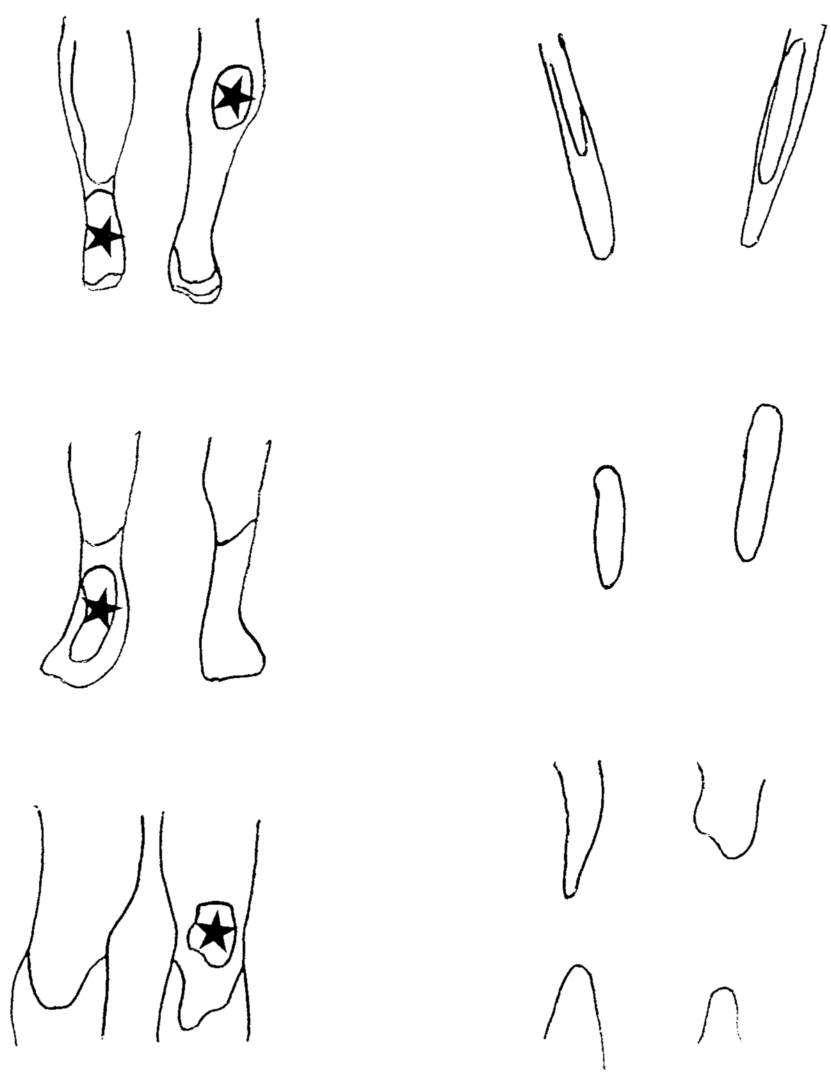


Figure 4

Effect of the contact thermograph's inability to visualize highly curved surfaces on its ability to detect critical asymmetries

The redrawn videothermograms on the left show the critical areas of asymmetry where marks on one limb are different from those on the pair in the same area. Note that the contact thermograph failed to make images of the critical areas because the curve was too great for the pillow to wrap around or get into. The top two images are of the front of the legs with the front of the ankles and sides of the legs missing in the contact thermograms. The bottom drawing is of the back of the legs with the backs of the knees missing in the contact thermographic views.

VIDEOTHERMOGRAM CONTACT THERMOGRAM



STABILITY OF TEMPERATURE ASYMMETRIES IN REFLEX SYMPATHETIC DYSTROPHY OVER TIME AND CHANGES IN PAIN

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ABSTRACT

Objective: To determine the clinical usefulness of skin temperature patterns for tracking Reflex Sympathetic Dystrophy (RSD) by assessing (a) long term relationships between changes in pain due to RSD and patterns of near surface blood flow and (b) relationships between site of pain and site of greatest asymmetries in near surface blood flow patterns.

Design: Multiple videothermographic evaluations of near surface blood flow patterns of subjects diagnosed as having RSD were performed. At each session, subjects filled in an outline of the body to show the location, intensity, and description of their pain. The thermograms were evaluated independently by two raters for location and intensity of pain, as well as location and degree of temperature asymmetries.

Setting: Two Army Medical Centers.

Subjects: Thirteen male and sixteen female subjects sequentially diagnosed as having RSD.

Outcome measures: Ratings of pain and videothermograms of the lower limbs.

Results: All but one subject were usually cooler on the most painful side by at least one half degree centigrade. The amount of relative coolness was not proportional to pain intensity. There were no consistent overlaps between exact location of pain and greatest thermal asymmetry. Seven subjects were thermally symmetrical on at least one recording. Six subjects were warmer on the affected side on at least one recording. One subject was always warmer on the affected side.

Conclusions: Videothermography is not an appropriate tool to use alone for either single session diagnosis or multi-session tracking of RSD.

INTRODUCTION

Reflex sympathetic dystrophy (RSD) is very difficult to diagnose and to track. One reason is that there is little agreement about the basic criteria which are useful in differentiating the syndrome from others. There is even considerable disagreement about whether "RSD" is one syndrome or a loosely related set of diagnostic indicators which could result from numerous, unrelated underlying pathologies. Even if RSD is a real syndrome, there considerable disagreement about how to diagnose it and whether any changes which appear to be mediated by the sympathetic nervous system (SNS) are actually related to the underlying cause of the problem.

The International Association for the Study of Pain's 1986 definition of RSD is "continuous pain in a portion of an extremity after trauma which may include fracture but does not involve a major nerve, associated with sympathetic hyperactivity" <1>. Several of the people most active in research on RSD, including Janig, Boas, Blumberg, and Campbell, recently published a "consensus" definition which helps in understanding why RSD is so difficult to define and diagnose <2>. By their definition, "RSD is a descriptive term meaning a complex disorder or group of disorders that may develop as a consequent of trauma affecting the limbs, with or without an obvious nerve lesion. RSD may also develop after visceral diseases, and central nervous system lesions or, rarely, without an obvious antecedent event. It consists of pain and related sensory abnormalities, abnormal blood flow and sweating, abnormalities in the motor

system and changes in structure of both superficial and deep tissues ("Trophic" changes). It is agreed that the name "RSD" is used in a descriptive sense and does not imply specific underlying mechanisms." Thus, both the current and the more traditional definitions of RSD call for it to be accompanied by altered blood flow in the affected limb <1, 3, 4>.

Virtually all of the heat emanating from the surface of the limbs is caused by and is proportional to near surface blood flow. Thermographic techniques are excellent ways to visualize the patterns of near surface blood flow because they accurately measure heat emanating from the skin. Videothermographs look very much like television cameras and work in a parallel manner. The basic difference is that heat emanating from the body's surface is recorded rather than the light reflected off of the surface as is done with a traditional video camera. Videothermographs can differentiate between temperatures of 0.1 C and can visualize areas ranging from one square centimeter to the entire body at once. A temperature reference appears on the screen so the actual temperature of an object being viewed is always known, and day-to-day comparisons can be made. The rationale and methodology for utilizing these devices in a clinical setting has been extensively reviewed elsewhere <5, 6 - 10>. Normative studies have shown that people's limbs usually differ by up to, but normally not greater than, half a degree C <5, 10 - 12>. Thus, differences between paired extremities are not normally considered significant until they reach at least one degree.

The highly consistent results of a number of studies indicate that thermograms of subjects with RSD will show significant coolness of the affected limb relative to the unaffected limb <13, 14 - 17>. Thus, thermography is a good way to initially detect asymmetries between the limbs which may indicate the presence of RSD as long as it is defined as including a significant temperature asymmetry between the affected and unaffected limbs. However, we are not aware of any objective studies which show (a) long-term relationships between changes in pain due to RSD and patterns of near surface blood flow, (b) changes in near surface blood flow patterns with successful treatment of RSD, or (c) relationships between site of pain and site of greatest asymmetries in near surface blood flow patterns. Until these relationships are established, the value of thermography for tracking the progress of RSD is in doubt.

METHODS

Subjects were diagnosed as having RSD according to the criteria set out in the International Association for the Study of Pain's "classification of chronic pain" <1>. Each was examined by an Orthopedic Surgeon who made the diagnosis entirely based on the results of a clinical examination without thermographic data. Other than hypersensitivity, all produced normal sensory examinations. Most of the subjects had relatively cool, clammy skin on the affected limb but this tended to change. Hair loss and glossy skin were usual among subjects who had RSD for over six months prior to beginning participation. As the study was evaluating consistency of temperature relationships between the limbs, the decision was made to include only those subjects who initially showed at least a 1/2 degree C difference between the affected and unaffected limbs. Some potential subjects may have been lost who did not show temperature asymmetries of at least 1/2 degree C at the initial evaluation. Thus, the results may be skewed against people with minimal asymmetries or frequent fluctuations of blood flow patterns who happened to be symmetrical during the initial evaluation. No subjects were included who showed any clinical evidence of (a) nerve or blood vessel damage, (b) current fractures, strains, or sprains, or (c) negative bone scans when such scans were performed. These exclusion and inclusion criteria are not those we would choose if we were starting the study over today. They are the criteria which were in use when most of the subjects were recruited for this longitudinal study. We have no way of determining how they would have appeared on reactive autonomic function and other tests currently used to aid in differential diagnoses. These patients are, however, typical of people given the diagnosis of RSD by clinical exam.

We performed multiple videothermographic evaluations (mean of 6.2, SD = 9.5, range =

2 - 54) of 29 sequential subjects diagnosed as having RSD (13 males and 16 females) using either Inframetrics 520, 535, or 600M model videothermographs. The participants had an average age of 33.6 years (SD = 14.81, range = 15 - 65) when they entered the study. Their average duration of RSD was 23 months (SD = 40.6, range = 1.0 - 192 months) when entering the study with 11 having had RSD for over 12 months. Sixteen of the subjects were treated with various modalities during participation. The demographic variables for each participant along with precipitating incident, duration of RSD, and major temperature and pain relationships are presented in the table.

TABLE ABOUT HERE

At each session, subjects filled in an outline of the body to show the location, intensity (on a scale of 0 - 10), and description of their pain. Subjects disrobed the affected limb and its pair 15 minutes prior to being thermographed so their skin temperature could equilibrate. The pain diagrams and thermograms were evaluated independently by two raters for number of degrees of asymmetry as well as location of pain and temperature asymmetries. A grid system which overlapped both the pain diagram and thermograms was used to map out the location and amount of surface area of reported pain and thermographic asymmetries.

Temperature asymmetries were evaluated at both 0.5 and 1.0 degrees C. This was done because most of the literature indicates that asymmetries are not definitely beyond the range of normal variation until they reach 1.0 degree C but may indicate a consistent pattern at 0.5 degrees C.

This investigation was not directly involved with any treatment modalities attempted. Many of the participants received treatment at some time during their participation by a variety of clinical groups unrelated to the authors. None of the participants were treated the same way, even when the same modality was used, so no treatment results were analyzed. They are, however, listed in the Table. Changes in pain and temperature potentially related to treatment were used only to test videothermography's ability to track the changes.

RESULTS

Every subject reported burning pain when filling out their pain diagrams. Several subjects reported pain of other descriptions in specific locations such as shooting pain at joints in addition to their burning pain.

Most subjects were relatively cooler on the painful side by at least one half degree centigrade at most sessions for most parts of the affected limb. However, the amount of relative coolness was not significantly correlated with pain intensity as they fluctuated (Spearman's $r = .15$; $p = 0.10$). For treated subjects, there was an overall significant change in pain when pre-to post-treatment readings were compared. For pain, the Wilcoxon matched-pairs test had a $z = -2.8$ and $p = 0.004$ while for temperature $z = -1.7$ and $p = 0.08$. Figure One illustrates relationships between changes in pain and asymmetry of skin temperature for a typical subject.

FIGURE ONE ABOUT HERE

The worst case situation for the usefulness of videothermography for detection of RSD would be if a subject who usually shows asymmetries happened to be evaluated on a day when the subject had no asymmetry. Three of our subjects had one evaluation each which were not asymmetrical at the 0.5 degrees C criteria and seven subjects had an average of 1.1 evaluations (SD = 0.4 , range = 1 - 2) which were not asymmetrical at the 1.0 degrees C criteria. Thus, seven of the 29 subjects would have been missed if only one thermographic evaluation had been performed and if the commonly accepted standard requiring one degree of difference between the limbs for clinical significance had been used.

Five subjects had 14 recordings (mean = 3.0, SD = 3.9, range = 1 - 10) in which the painful

side was warmer than the paired extremity. Another subject's painful side was consistently warmer for all 12 evaluations. A seventh subject, who was evaluated 54 times at various intervals over a three year period, had 14 sessions during which the painful side was warmer. Thus, if only one evaluation had been performed, six of the 29 subjects could have produced abnormal results not usually associated with RSD.

There was no correlation between changes in pain and other known factors including age, months with RSD, or the affected side being relatively warm or cool. Figure Two illustrates the changing relationships between pain and temperature asymmetry over a three year period in one subject.

FIGURE TWO ABOUT HERE

The amount of area covered by asymmetries in temperature correlated with the degrees of asymmetry (Spearman's r = 0.36, p 0.001) and the amount of area which was drawn on the pain diagram as painful correlated with the overall intensity of pain reported (Spearman's r = 0.31, p 0.001). The amount of area covered by temperature asymmetries and the amount of area covered by the pain correlated significantly (Spearman's r = 0.46, p 0.001) but there were no consistent relationships between exact location of pain and thermal asymmetry. Areas were calculated based on the grid system described in the method section. Thus, the amount of area which is painful increases with both overall amount of pain, the amount of area covered by temperature asymmetries, and the extent of the asymmetry. However, the painful and asymmetrical areas are not similar in location and do not have consistent positional relationships across subjects. Figure Three illustrates relationships between a subject's indications of pain location and videothermographic asymmetries.

FIGURE THREE ABOUT HERE

There were no significant correlations between the original cause of the pain or limb in which RSD appeared and the severity or location of RSD related pain among the subjects.

DISCUSSION AND CONCLUSION

This study demonstrated that videothermography is not a simple tool to use in initial evaluation or in tracking the progress of RSD. As temperature changes are usually not proportional to changes in pain intensity, surface heat patterns can not be used as a way to predict how much pain the patient is likely to be experiencing. However, the amount of surface reported as being painful does correlate with the amount of surface showing temperature asymmetries.

The number of times in which subjects failed to show significant asymmetries at one or more sessions when pain was reported indicates that the technique could miss the diagnosis when being used for initial evaluation. These results show that neither (a) lack of decreased temperature in the affected limb, (b) relatively greater warmth in the affected limb, nor (c) lack of a thermal difference between the limbs, can be used to rule out RSD. However, when the affected limb is significantly cooler than the unaffected limb, there is little doubt that a real problem exists which needs further clinical evaluation. Just what problem has been detected is open to considerable doubt. Many pain syndromes in the back, legs, and feet produce concomitant reductions in blood flow to the affected limb for a wide variety of reasons. For example, one foot can be significantly cooler than its pair for several diagnostic types of low back pain related to nerve constriction in the back <18 - 20>. Other conditions, including diabetes and vibratory stress, can cause increases in blood flow to one foot relative to the other <21, 22>.

This study also demonstrated that people with long term RSD show unstable heat patterns

over multiple recordings. The painful limb is likely to be relatively warmer or cooler than the pain free limb, apparently at random with respect to the factors we recorded. Thus, the debate over whether the painful limb is cooler or warmer among patients have RSD of long duration is due to recordings being done only once on each patient. With only one recording, it would be almost random whether the affected limb was cooler or warmer than the unaffected limb.

Hobbins <23> stated that the results of videothermographic evaluations of RSD may be quite variable because the sympathetic nervous system is disabled and functioning almost randomly. His recommendation for determining whether sympathetically maintained pain is present is to test the autonomic nervous system's ability to react normally through "challenges" such as putting a hand into warm water and thermographically observing the other extremity. We did not do this with our subjects. Perhaps such challenges presented at each recording would produce more consistent results since sympathetic reactivity might change along with pain and other symptoms.

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LEGEND FOR TABLE:

OVERVIEW OF PARTICIPATING SUBJECTS

Average pain intensity across sessions is rated on a scale of 0 <no pain> - 10 <most pain imaginable> and average number of degrees of asymmetry across sessions indicates the average number of Celsius degrees by which the effected limb is cooler than the normal pair in the most usual location.
Treatments: PT = active physical therapy without passive movement; Block = series of temporary sympathetic blocks; BFB = training to raise the temperature of the fingers or toes; None = no treatment during participation in the study.

Table

OVERVIEW OF PARTICIPATING SUBJECTS

(Average pain intensity across sessions is rated on a scale of 0 <no pai - 10 <most pain imaginable> and average number of degrees of asymmetry across sessions indicates the average number of Celsius degrees by whick the effected limb is cooler than the normal pair in the most usual location.)

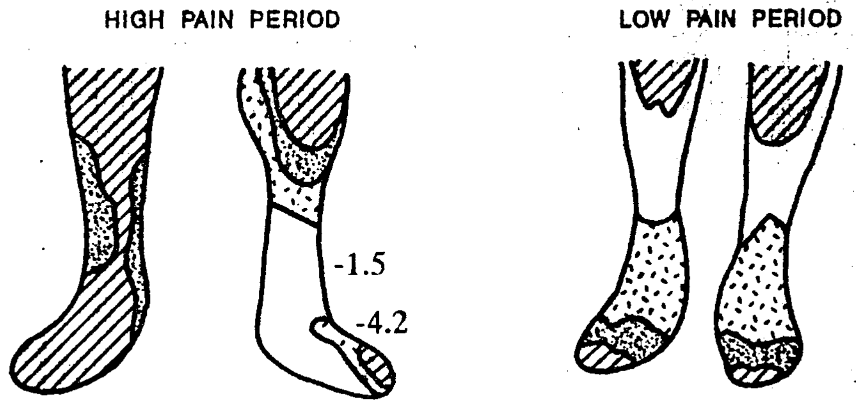
SB #	SEX	AGE YRS	PRECIPITATING PROBLEM	MONTHS OF RSD	NUMB THRML EVALS	LOCATION & INTENSITY OF PAIN		LOCATION DEGREES C ASYMMETRY	
1	m	18	cellulitis	3	4	foot	10	calf	1
2	m	27	run/march	48	8	knee	8	ankle	2
3	f	61	fall	72	2	knee	4	calf	3
4	f	15	tear/stretch	4	3	ankle	10	heel	2
5	f	42	unknown	1	4	low leg	8	heel	2
6	m	19	fracture	6	4	foot	9	heel	2
7	m	36	fracture	1	2	ankle	3	heel	5
8	f	35	surgery	?	6	foot	9	low leg	3
9	m	30	run/march	4	5	foot	7	ankle	1
10	~~f~~	17	fracture	4	2	leg	7	low leg	
11	f	64	fall	18	6	leg	4	calf	
12	m	29	tear/stretch	1	12	ankle	4	toe	-
13	f	.	unknown	78	6	foot	10	ankle	
14	m	44	blunt trauma	18	2	ankle	6	heel	
15	f	24	tear/stretch	18	4	foot	8	ankle	
16	f	27	surgery	1	3	hand	4	forearm	
17	m	24	tear/stretch	15	6	ankle	4	ankle	
18	f	38	surgery	1	7	foot	3	toes	
19	m	25	blunt trauma	?	2	leg	10	foot	-
20	f	41	infection	3	2	hand	2	arm	
21	f	17	unknown	48	4	foot	5	foot	
22	m	.	tear/stretch	1	1	ankle	5	ankle	
23	f	65	fall	2	4	low leg	3	calf	
24	m	26	laceration	11	3	leg	4	thigh	
25	m	30	fracture	24	4	arm	4	fingers	
26	f	34	fall	18	6	hand	4	forearm	
27	m	20	fracture	12	2	hand	6	hand	1
28	f	56	fracture	192	9	arm	7	fingers	
29	f	24	tear/stretch	60+	54	foot	7	toes	

Figure 1

CHANGES IN PAIN CORRESPONDING TO CHANGES IN RELATIVE LIMB TEMPERATURE

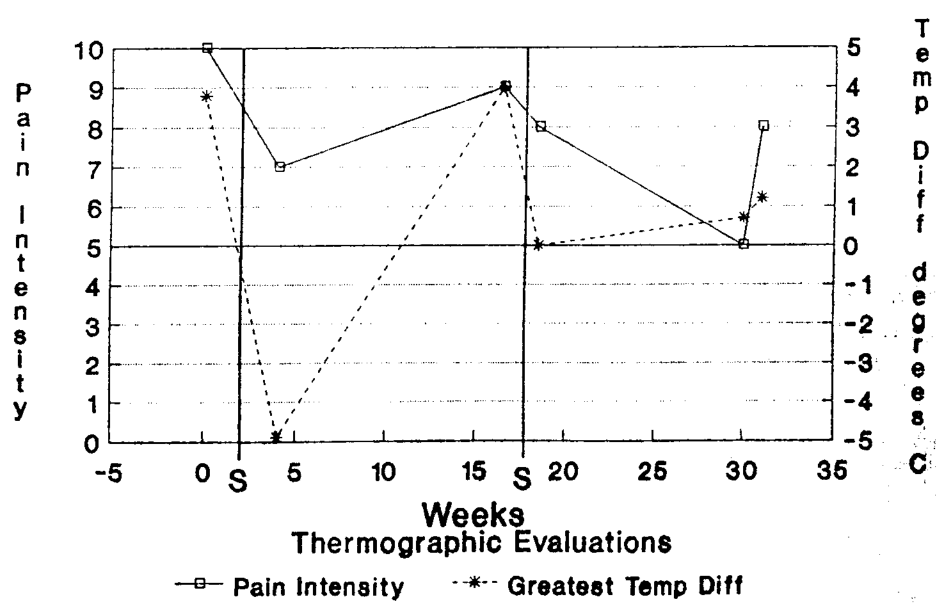
CHANGES IN TEMPERATURE PATTERNS:

Redrawings of colored videothermagrams indicate differences in temperature patterns when asymmetries are at least 1/2 degree C during periods of high and low pain



CHANGES IN RELATIONSHIPS OVER TIME:

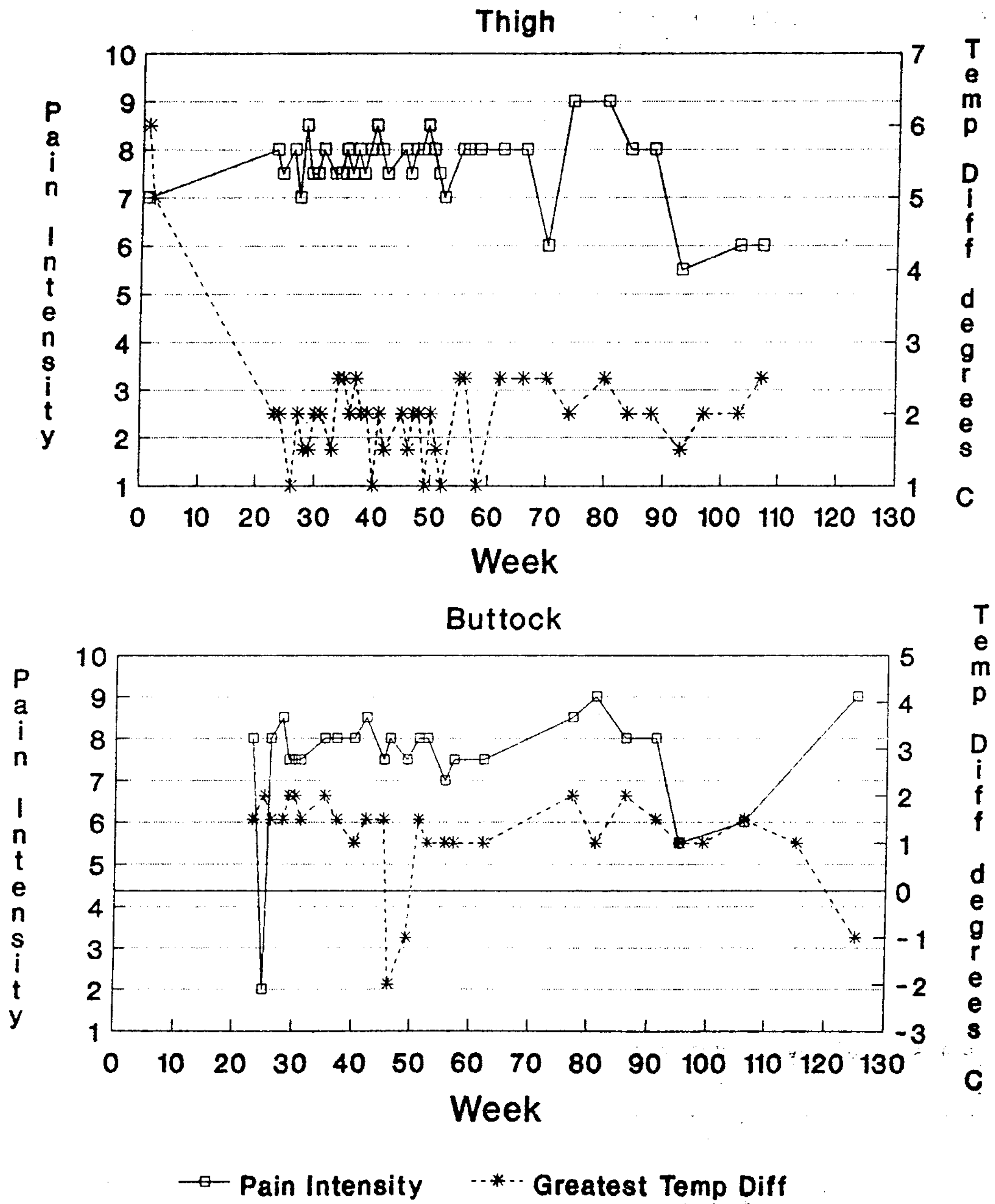
(Right axis - numbers are positive when painful limb is cooler than normal limb)



S = Sympathetic Block

Figure 2

Relationships between pain and temperature asymmetry over a two year period in one subject

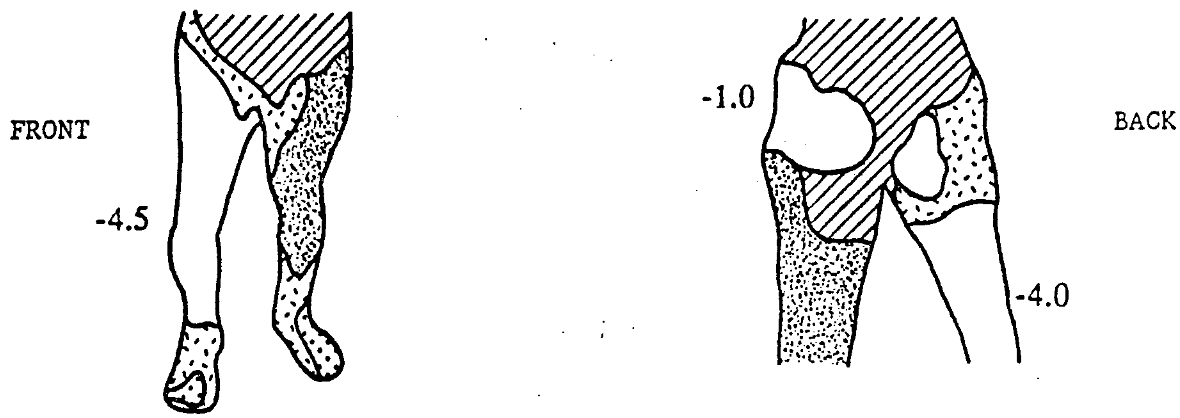


(Positive numbers on the right axis indicate painful side is cooler than pain free side and vice versa.)

Figure 3

RELATIONSHIPS BETWEEN LOCATION AND SIZE
OF
TEMPERATURE ASYMMETRY AND PAIN

Redrawings of colored videothermograms indicate differences in temperature patterns when asymmetries are at least 1/2 degree C:



Subject's illustration of pain patterns, descriptions, and intensities (on a scale of 0 - 10) when the above thermograms were taken: